Updates to OCO-2 X_{CO2}, data products, new science, and future perspectives

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and

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December 13, 2018

Background

- XCO2 from space has been consistently refined over the last 10+ years
- Errors and biases of several ppm have been reduced to consistently less than 1 ppm.
- Important science is (and can be) done with these error levels, though further reductions are still highly desirable!

MILESTONES

GOSAT 2009-present

- ACOS versions 2.8, 2.9, 2.10, 3.3, 3.5, 7.3
- Many other retrievals as well; strong intercomparison efforts
- Random errors ~1ppm; biases ~ 0.6 ppm

OCO-2 2014-present

- ACOS versions 7, 8, 9
- Some intercomparisons
- Random errors ~0.5 ppm; biases ~ 0.8 ppm

B8 Successes

- Removed “southern ocean” bias due to addition of a stratospheric aerosol term in the retrieval
  - This mitigated effects from both real UT/LS aerosols, PLUS icing effects on the O2A band detector.
- Systematic errors significant reduced relative to B7.
- Agreement between land nadir, land glint, and ocean improved.

Atmos. Meas. Tech., 11, 1–38, 2018
https://doi.org/10.5194/amt-11-1-2018

Atmospheric Measurement Techniques
Open Access
EGU

Improved retrievals of carbon dioxide from Orbiting Carbon Observatory-2 with the version 8 ACOS algorithm

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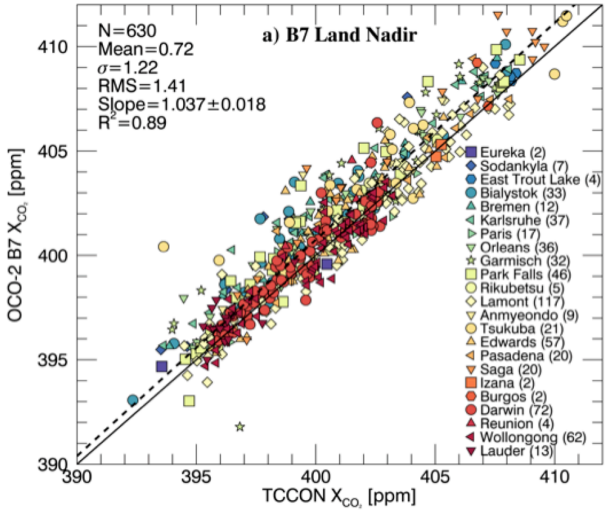
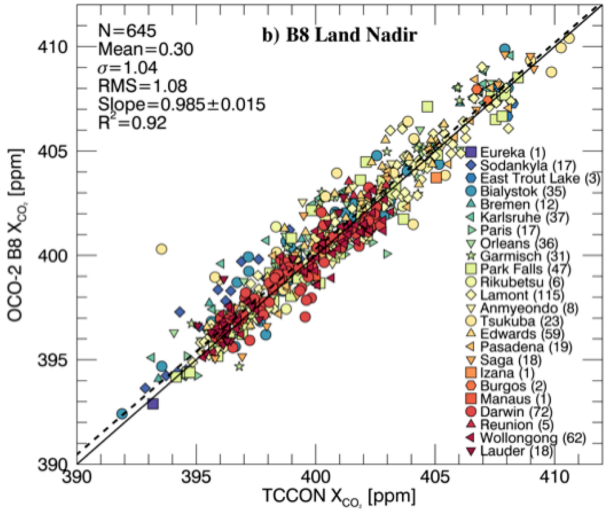
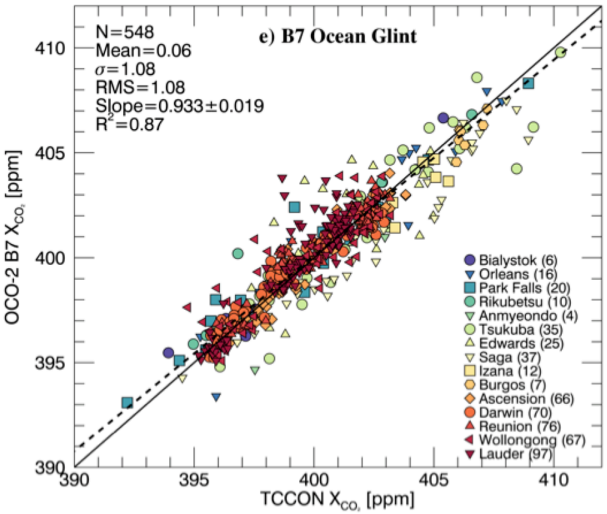
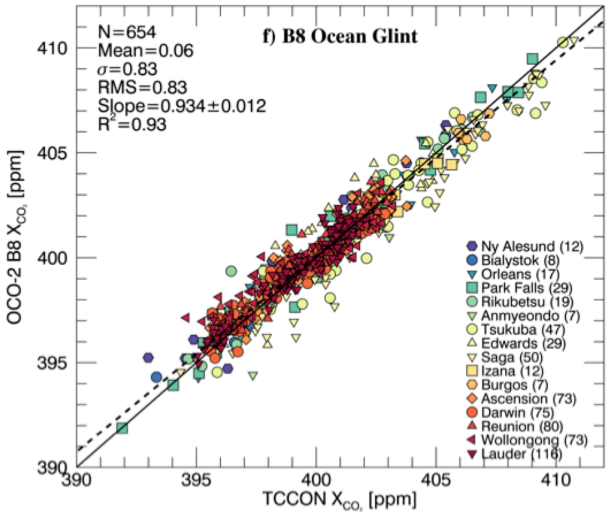
B8 reduced XCO2 errors
vs. TCCON









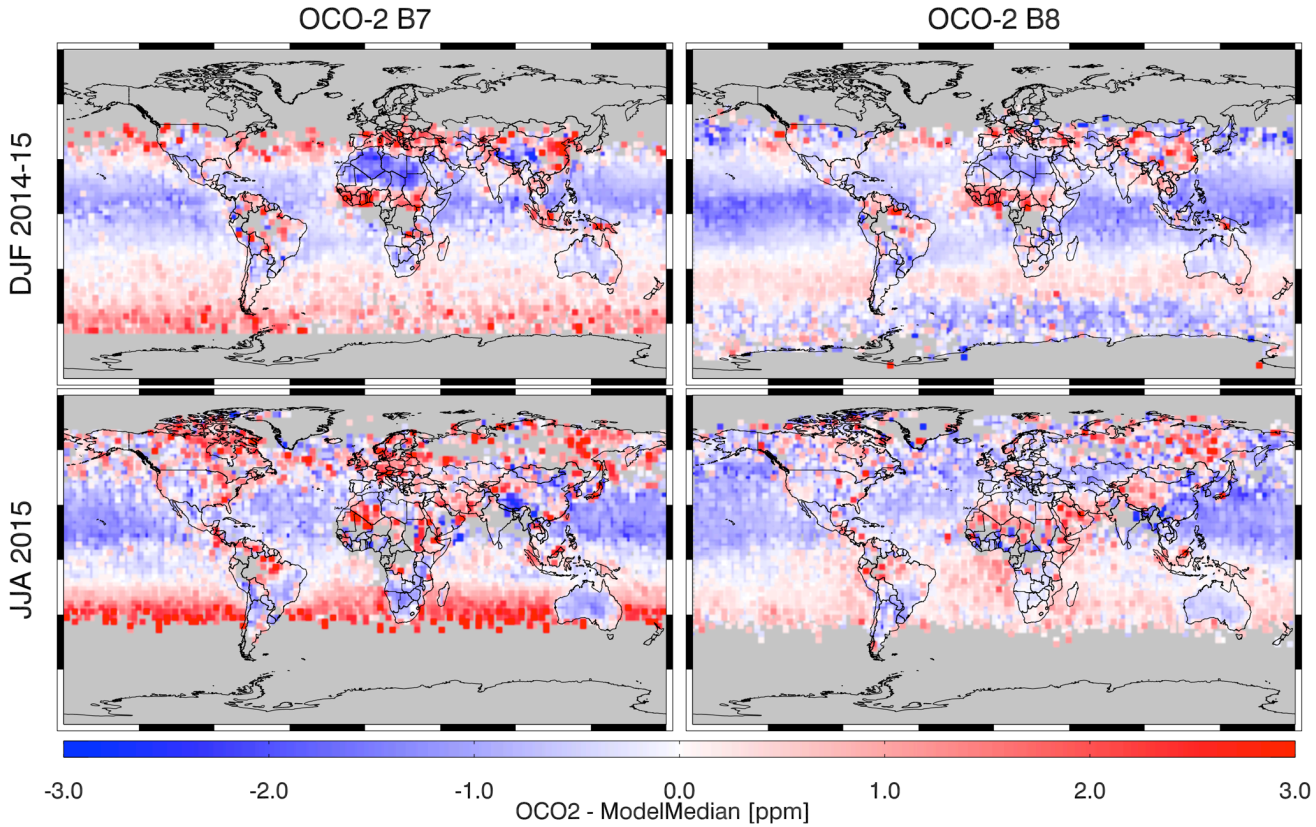
Land (Nadir)

25% Reduction in Error Variance

Ocean (Glint)

40% Reduction in Error Variance

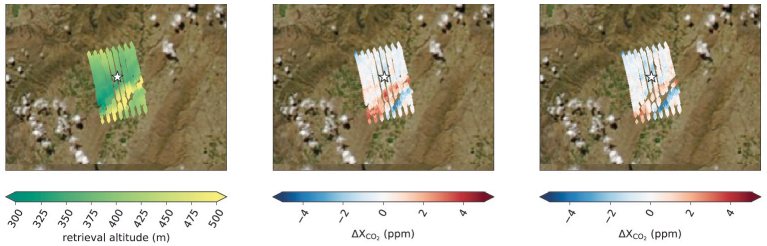
B8 reduced XCO2 errors
vs. Models

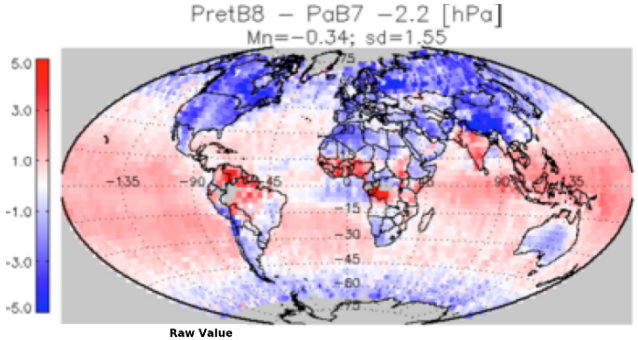


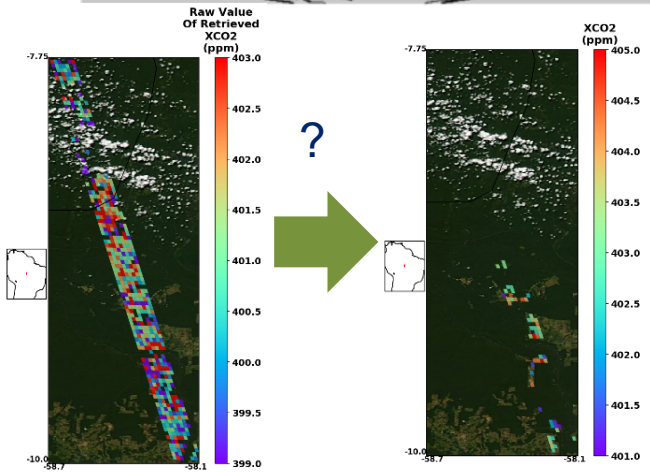
- Comparison to ensemble median of 9 models where they agree.
- Bias patterns significantly reduced
- Ocean coverage at higher SZAs extended
- Some important differences to the model median remain

Known Issues with the OCO-2 B8 Product

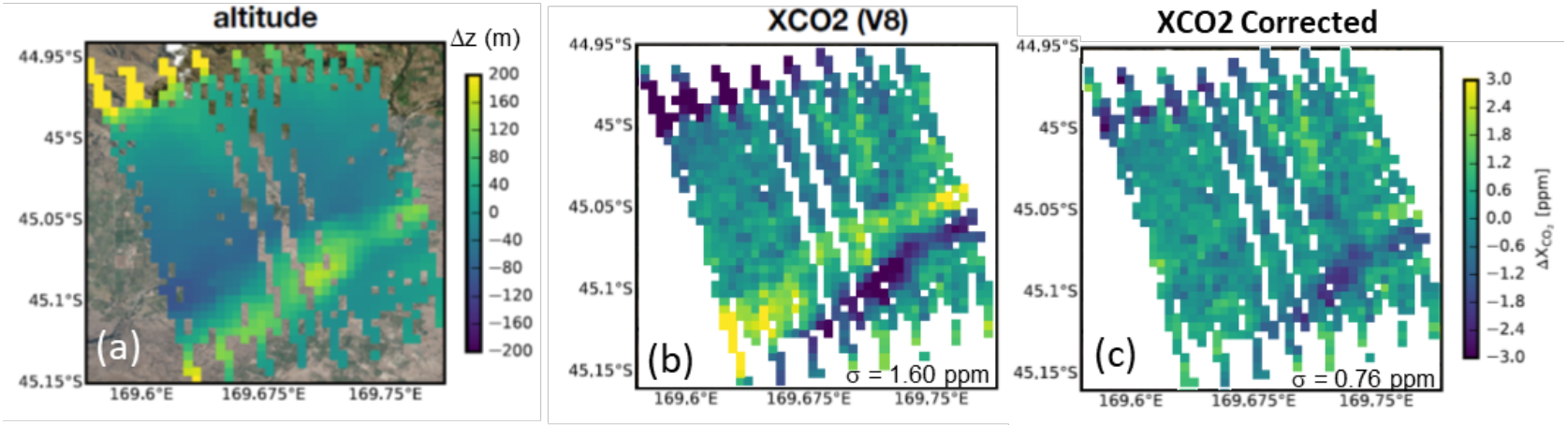
- Small (~0.06°) Pointing/Geolocation errors introduces systematic biases in regions with significant topography
- A pole-to-pole surface pressure bias was introduced by the updated A-band gas absorption coefficients
- Comparisons with TCCON show a slight long-term drift in the X_{CO2} product, losing 0.1-0.2 ppm/yr.
- Dark surface albedo screening is too aggressive







The Pointing Offset

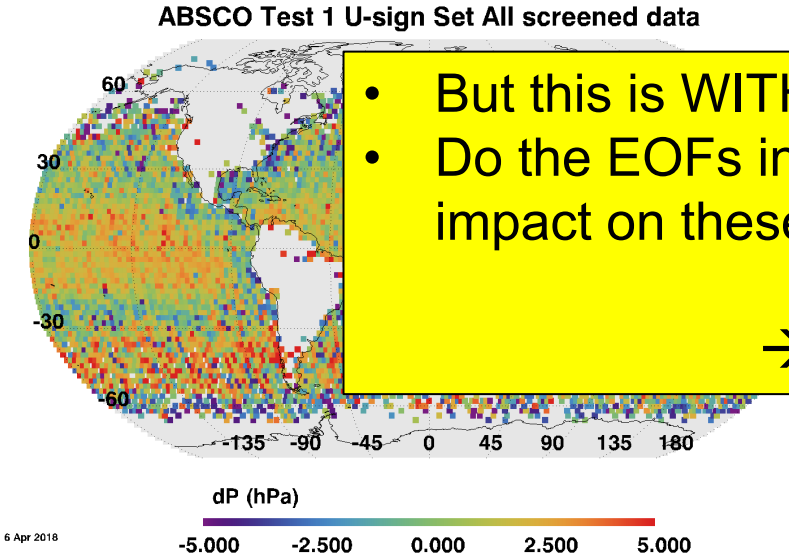


Matt Kiel and Paul Wennberg

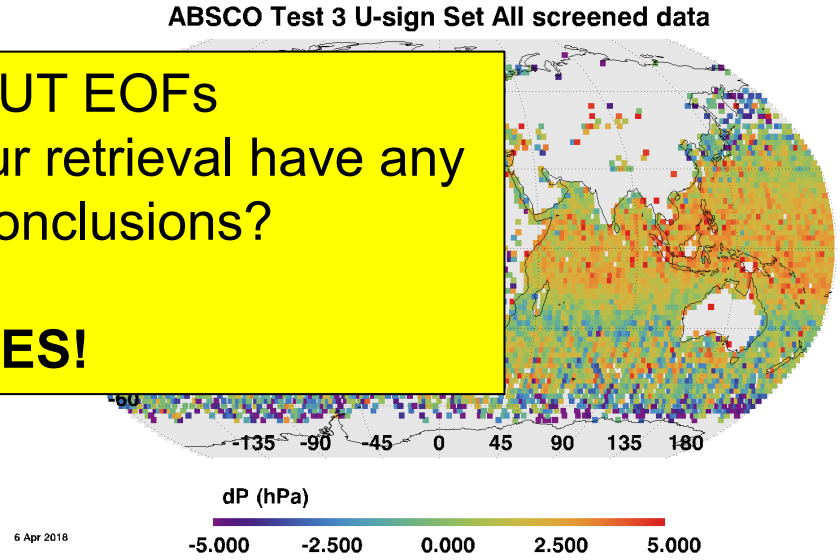
- OCO-2 observations of the Lauder TCCON station and other regions with moderate to large topographic variability show strong correlations between topographic slope and X_{CO2} bias (b).
- These errors were traced to a small (0.06°) pointing error that was <1/6 the angular size of the sounding footprint.
- Correcting the pointing error reduced by X_{CO2} bias by more than half.
- See posters by Matt Kiel et al. (A51R-2501)

Surface Pressure Bias due to Uncertainties in O_2 Absorption Cross Sections

V7 Baseline with Version 4.2 ABSCO



V7 Baseline with Version 5.0 ABO2 ABSCO



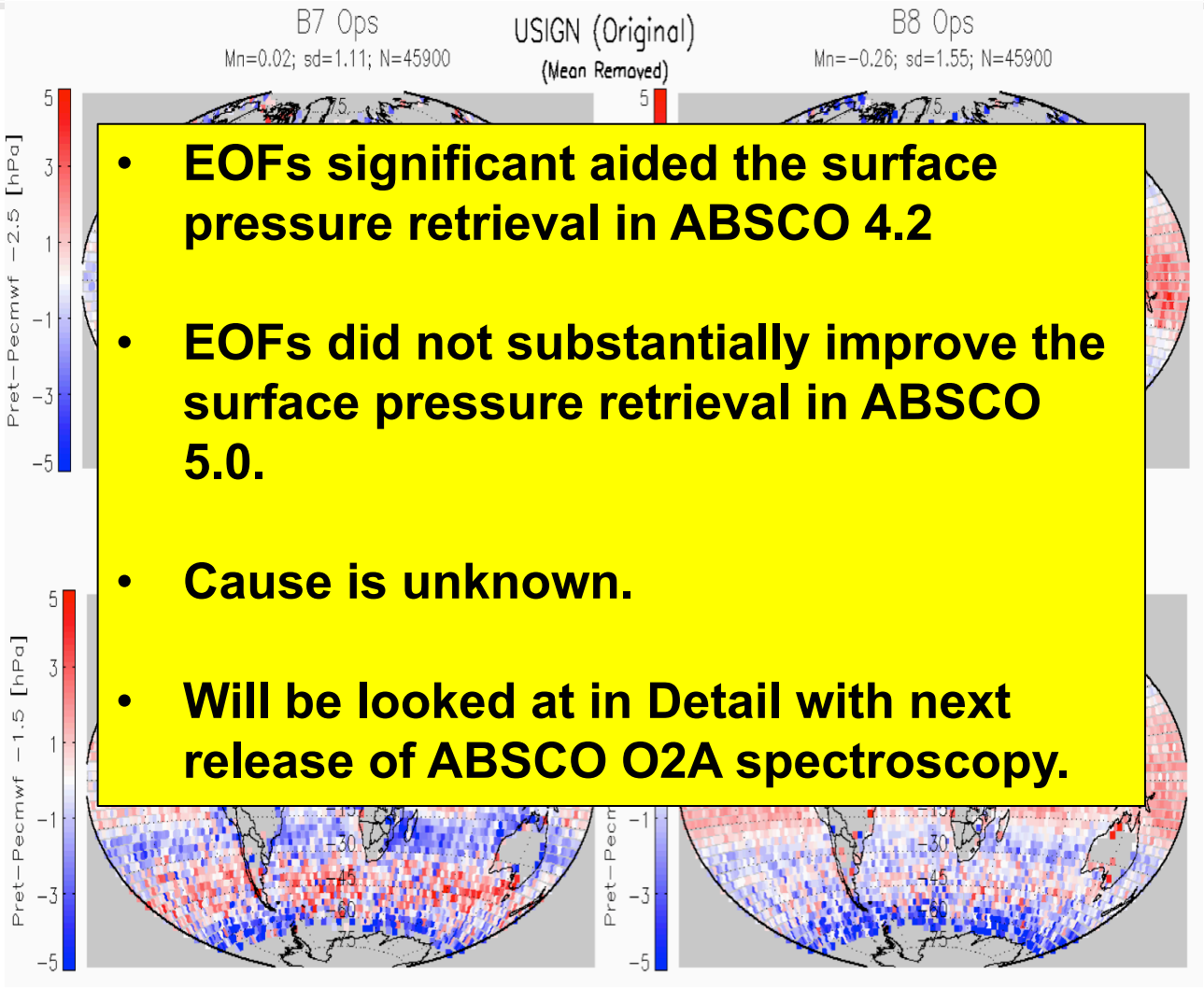
- But this is WITHOUT EOFs
- Do the EOFs in our retrieval have any impact on these conclusions?

→ **YES!**

- Version 5 O_2 gas absorption coefficients (ABSCO, right) substantially reduced the amplitude of land/sea and ocean glint surface pressure biases and scatter seen in Version 4.2 ABSCO (left).
- However, it apparently introduced a larger, more coherent pole-to-pole bias.
- This difference is well compensated in the bias-corrected X_{CO2} data included in the V8 Lite files.

Brendan Fisher and Vivienne Payne

Impact of EOFs on Surface Pressure Retrieval



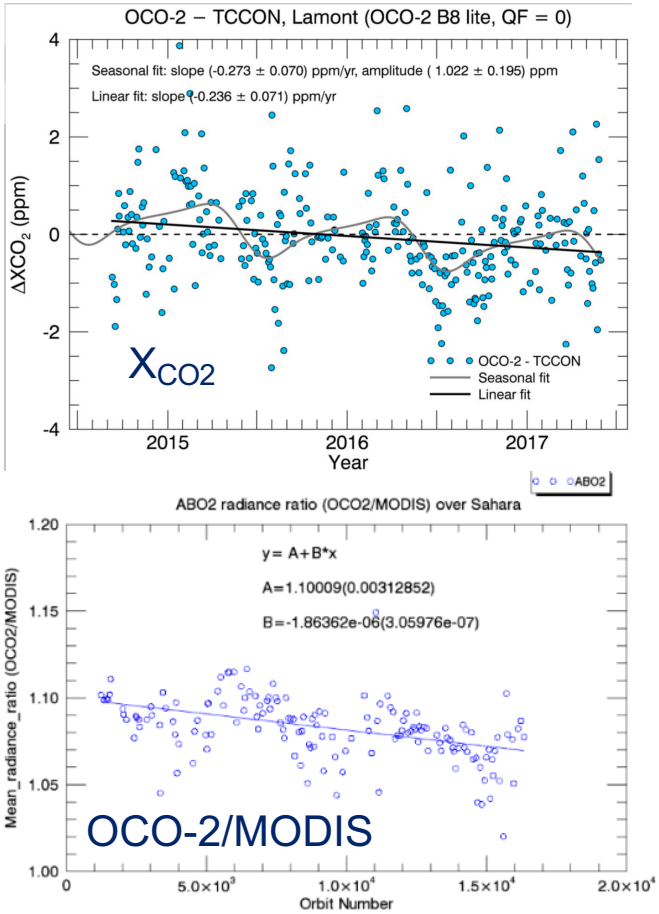
- **EOFs significant aided the surface pressure retrieval in ABSCO 4.2**
- **EOFs did not substantially improve the surface pressure retrieval in ABSCO 5.0.**
- **Cause is unknown.**
- **Will be looked at in Detail with next release of ABSCO O2A spectroscopy.**

with EOFs

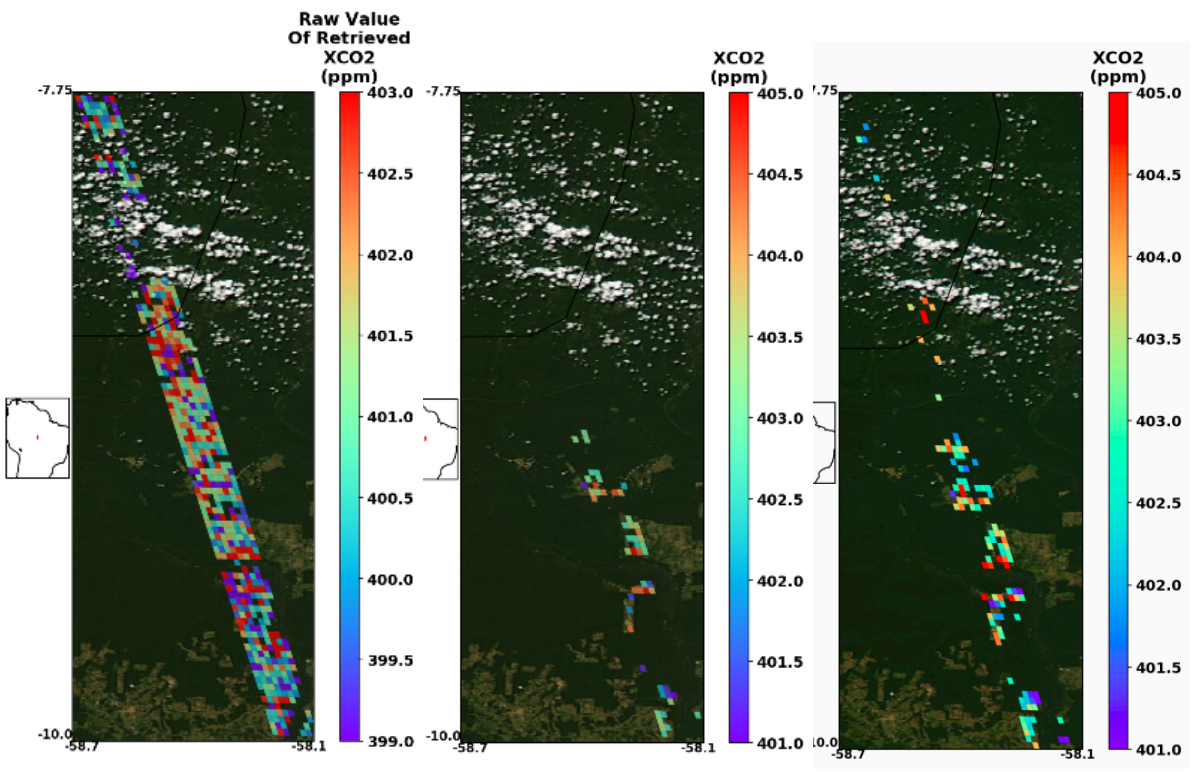
without EOFs

Long Term Radiometric Drifts

- Comparisons of the OCO-2 V8 product with TCCON and Models indicate a long-term drift (-0.1 to -0.2 ppm/yr)
- This drift appears correlated with a long term drift in the radiometric calibration of the V8 L1b product
  - OCO-2 was cross calibrated against MODIS Aqua over the Sahara
    - Location box: 15° -23° N, 5° -17.5° E
  - Differences in viewing geometry (BRDF) and spectral interpolation may account for overall biases (based on RRV experience)
  - Comparisons indicate ABO2 (O_2 A-band) channel has a drift of -0.9% / year
- This drift will be corrected in the next build of the OCO-2 algorithm (B10)



Why is the XCO_2 Yield so Low over Cloud-free Forests?



B8 All Data | B8 Good QF | B9 Good QF

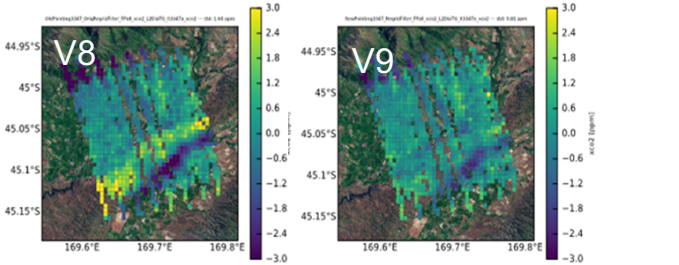
- Many cloud-free soundings are being lost over dark forests
- These soundings are being removed by the strong CO_2 low albedo land filter
- Many of these soundings can be recovered by adjusting this filter (at the possible expense of higher scatter)
- B9 fixed some of this, although still could use improvement.

The OCO-2 V9 Product

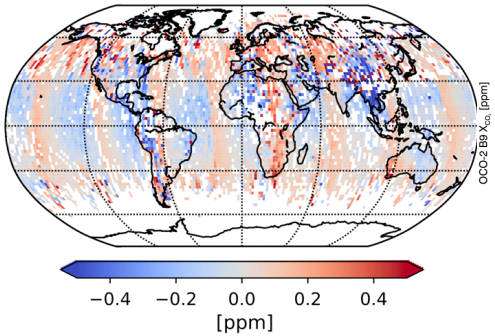
- The OCO-2 Team released the Version 9 (V9) product on 10/15.
  - refined pointing
  - a correction to the prior meteorology
  - updated filtering and bias correction
- These updates
  - reduce bias in the presence of rough topography
  - Provide better sampling over topical and boreal forests with slightly more scatter
- This new dataset is available through the GES-DISC

https://disc.gsfc.nasa.gov/datasets?keywords=oco-2&page=1

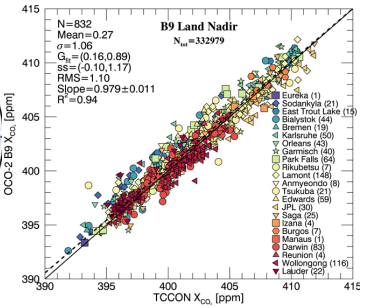
- See B. Fisher poster (A51R-2513) for more details.



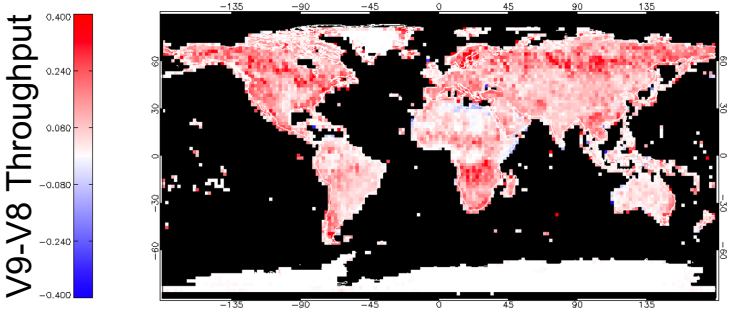
Pointing Correction Reduces XCO_2 Bias



XCO_2 Differences: V8 - V9

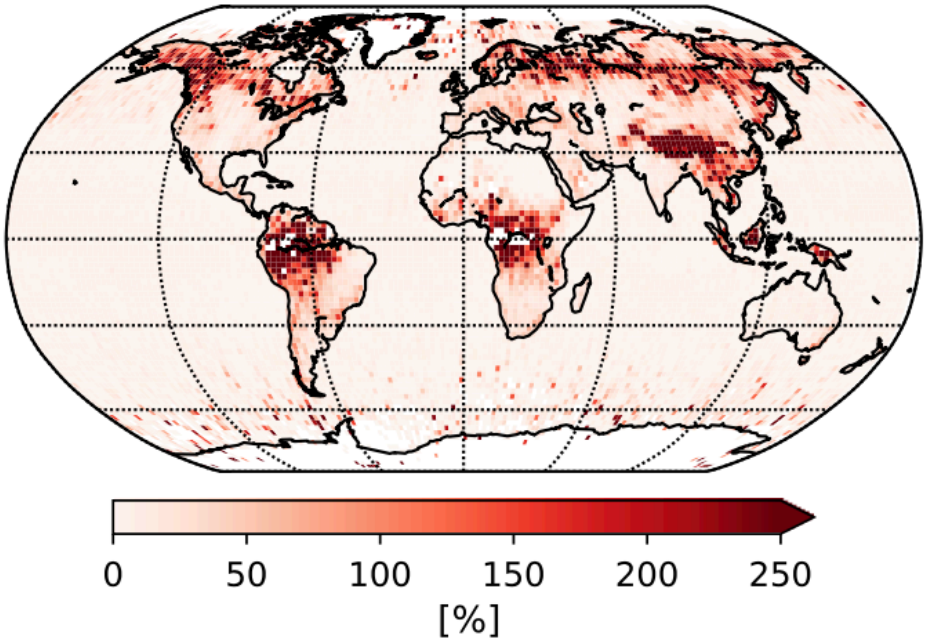


V9 vs TCCON

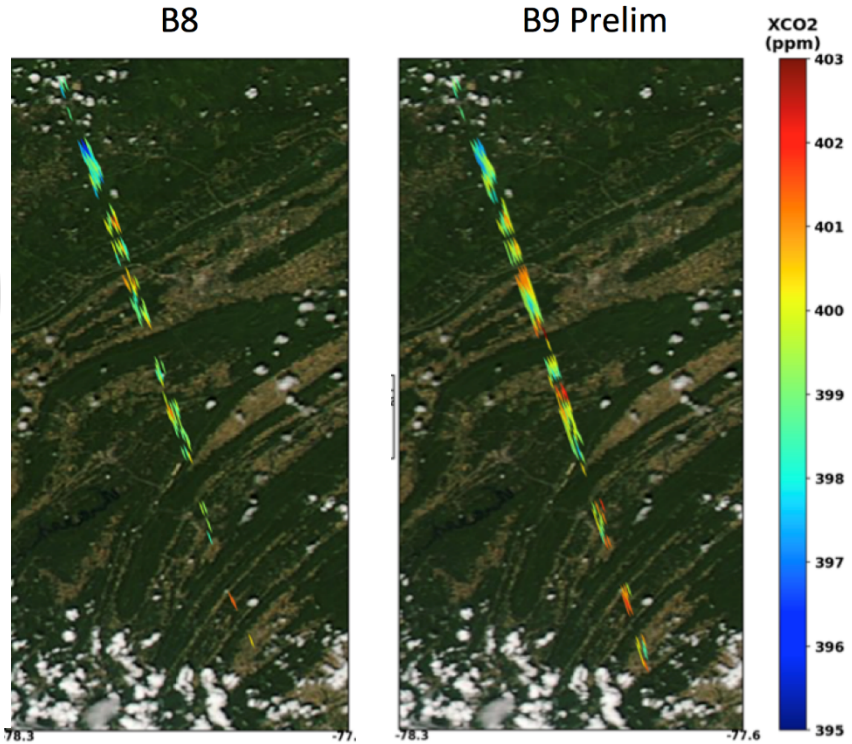


Improved Coverage over Tropical and Boreal Forests

Improved Yields



Matt Kiel et al., AMTD 2018



Emily Bell (CSU)

The pointing correction, combined with re-tuned quality filters improved the yield, especially in regions with rough topography and dark surfaces.

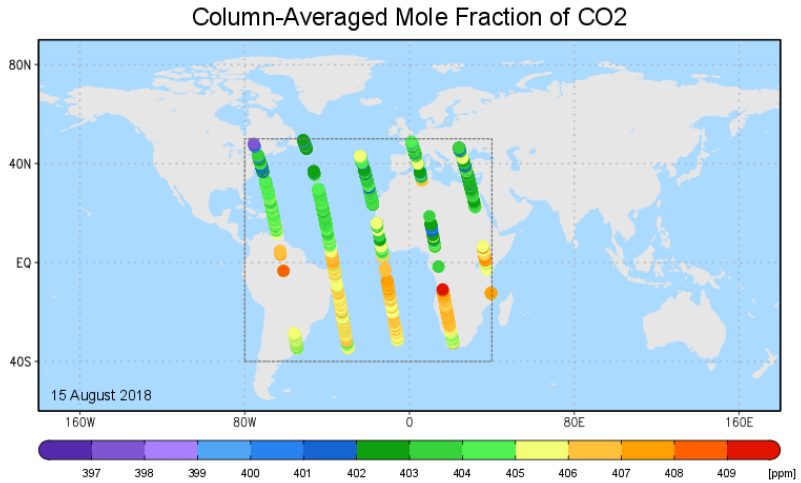
Subsetting Capability Added for OCO-2 "Lite" Files

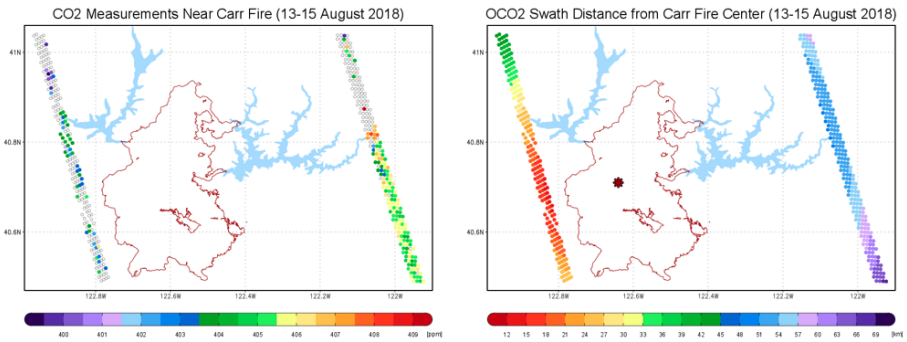
- OCO-2 and ACOS Level 2 "Lite" files can now be subsetted spatially and by variable
  - Spatial subsets may be selected within a bounding box or within a user-defined radius around a user-specified location ("point+radius subsetting")

- This service is now operational

https://disc.gsfc.nasa.gov/information/news?title=Subsetting%20capability%20added%20for%20OCO-2%20%22Lite%22%20files

- Questions:
  - Dana Ostrenga, Thomas Hearty, Paul Huwe, Jennifer Adams, Andrey Savtchenko, Jerome Alfred, Lena Iredell





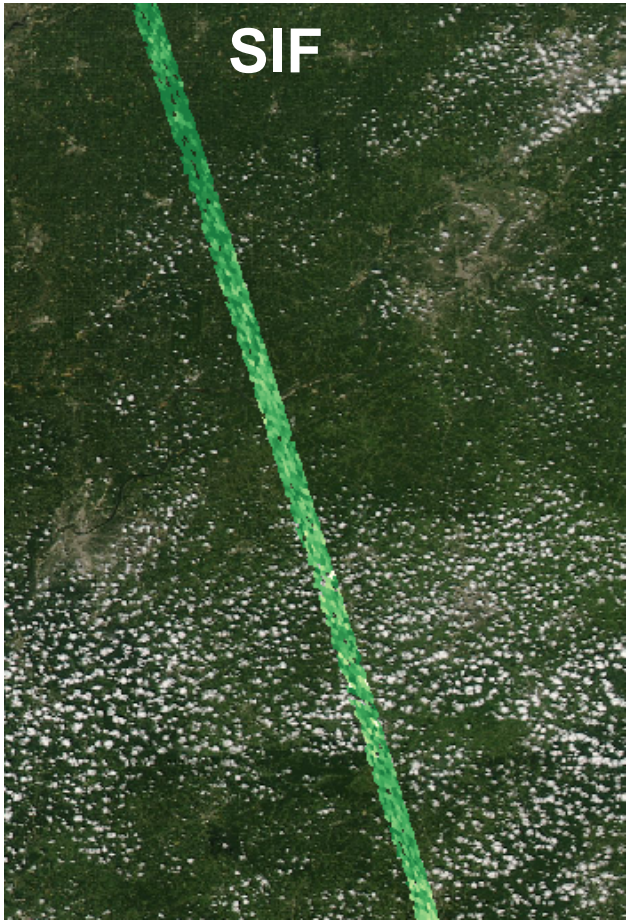
Left: XCO2 for two OCO-2 orbits from 13 (left) and 18 Aug (right) that passed within 100 km of the Carr Fire.

OCO-2 Data Coming to NASA's Worldview in Early 2019

- *Variables*
  - **Bias-corrected, Quality-filtered XCO2**
  - **Bias-corrected, Quality-filtered XCO2 with the NOAA ESRL daily global mean XCO2 subtracted**
  - **Total Column Water Vapor**
  - **SIF at 757 nm**
  - **SIF at 771 nm**
  - **Blended SIF**

Worldview: https://worldview.earthdata.nasa.gov/

NOAA ESRL Daily Global Mean XCO2: ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_trend_gl.txt



OCO-2 overpass of the Ghent Generating Station in Kentucky on August 13, 2015

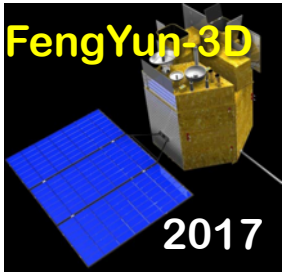
On to Version 10

- Known changes:
  - Fix small bugs (IMAP preprocessor affects cloud screening fidelity)
  - Fully implement met resampler fix
  - Updated O_2A-band spectroscopy (with hopes to improve the surface pressure retrieval)
- Items being explored:
  - Time Trend in XCO2 data (~ -0.1 to -0.3 ppm/yr). Cause? How to fix?
  - Surface pressure prior constraint.
  - Aerosol scheme. (Nelson's new scheme? Other?)
  - Better merging of quality flag and warn levels.
  - Many others: radiance offsets, SIF treatment in L2, solar continuum model, quadratic albedo fit, better posterior uncertainty, co2 prior constraint, 3D cloud correction.
- Expected completion time frame: Summer 2019???

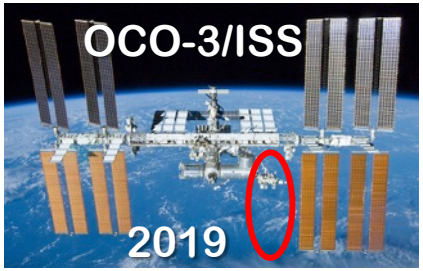
Retrieval Improvements may impact all these present and future satellites

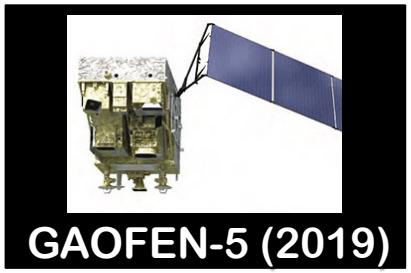
PAST

PRESENT

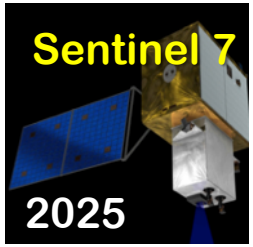


NEAR FUTURE

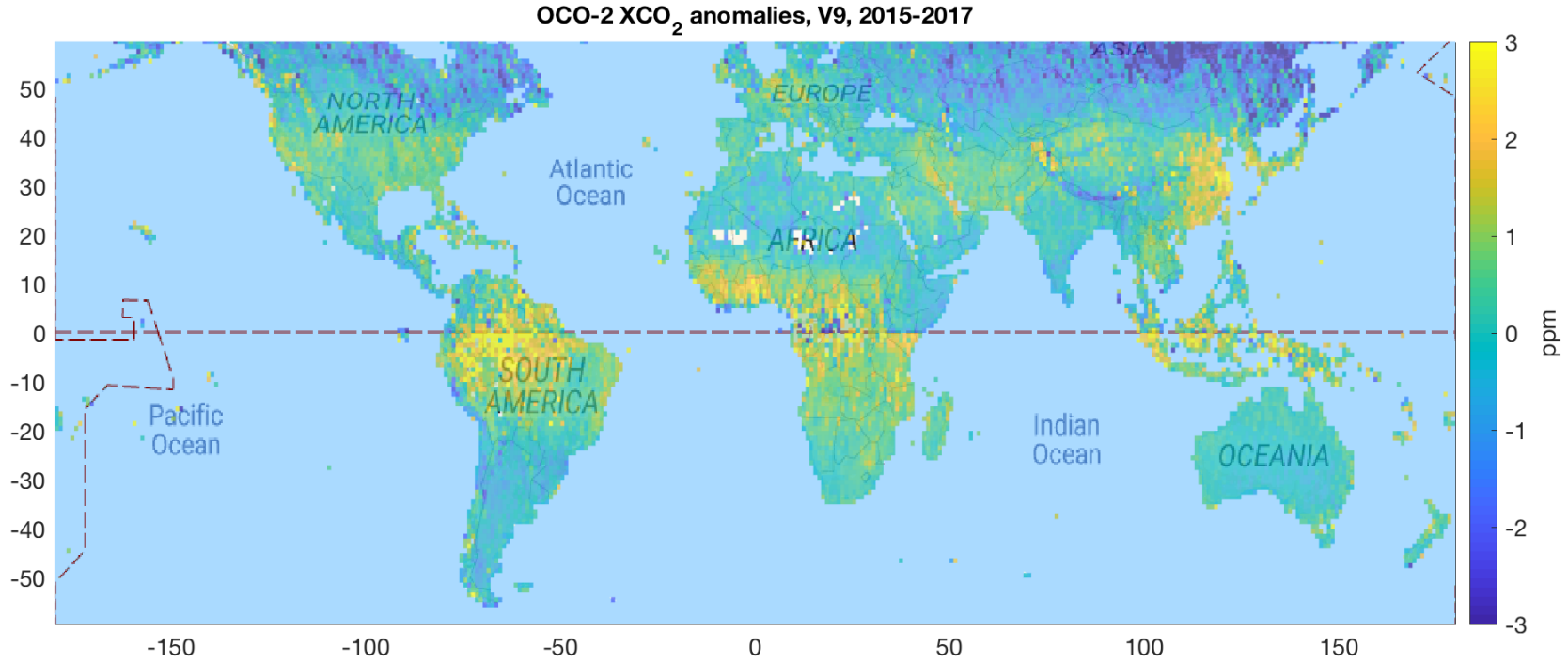




LATER

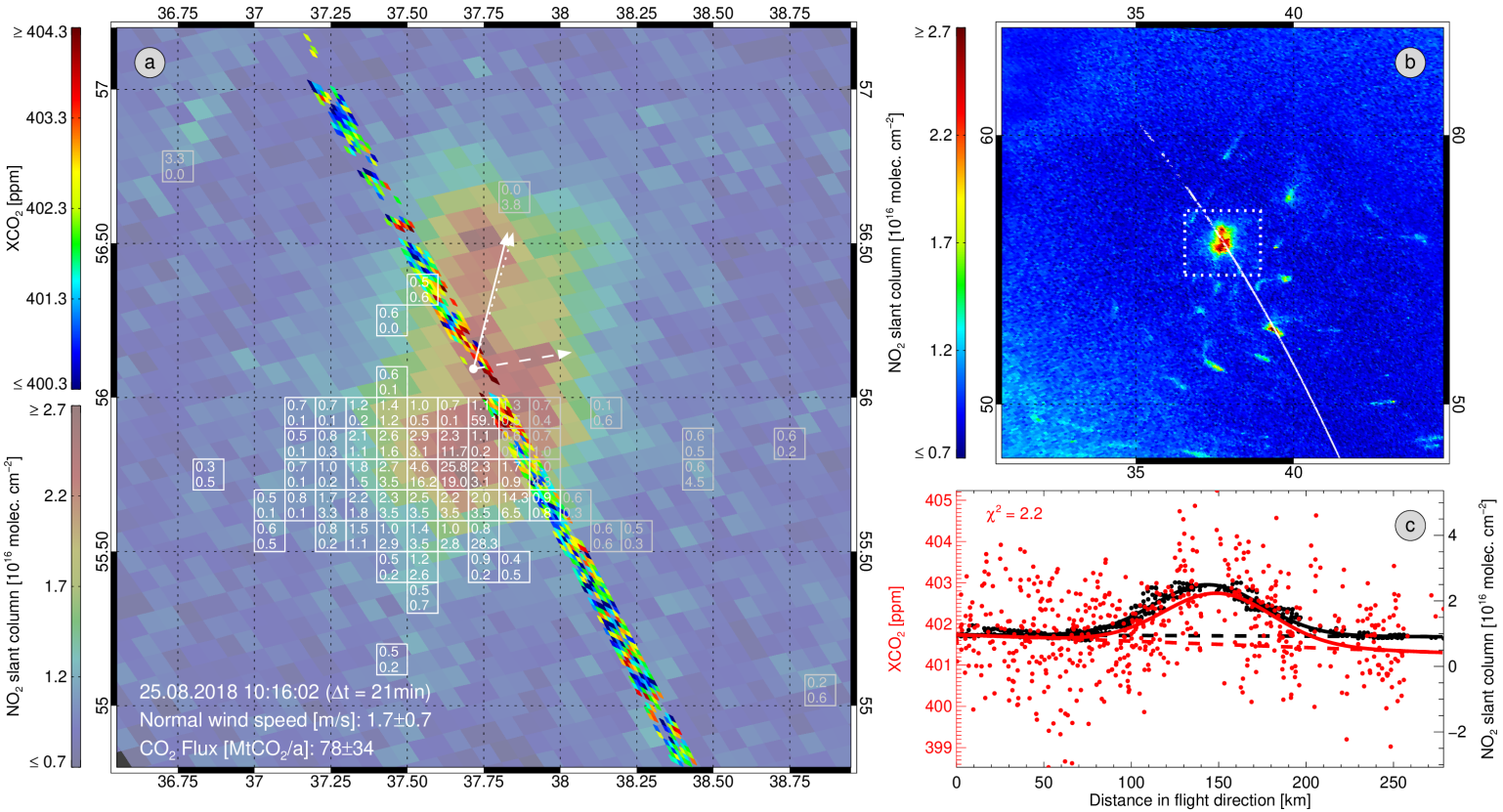


Persistent X_{CO2} Anomalies (Hakkarainen et al.) Comparison of the V8 and V9 Products



- OCO-2 XCO_2 estimates are being used to quantify persistent anomalies associated with CO_2 emissions (sources) and uptake (sinks) [Hakkarainen et al. Atm. Chem. Phys.2018]
- While the V8 and V9 anomalies are similar, the V9 product has much less scatter in areas with rough topography (i.e. Himalayas, Canadian Rockies)

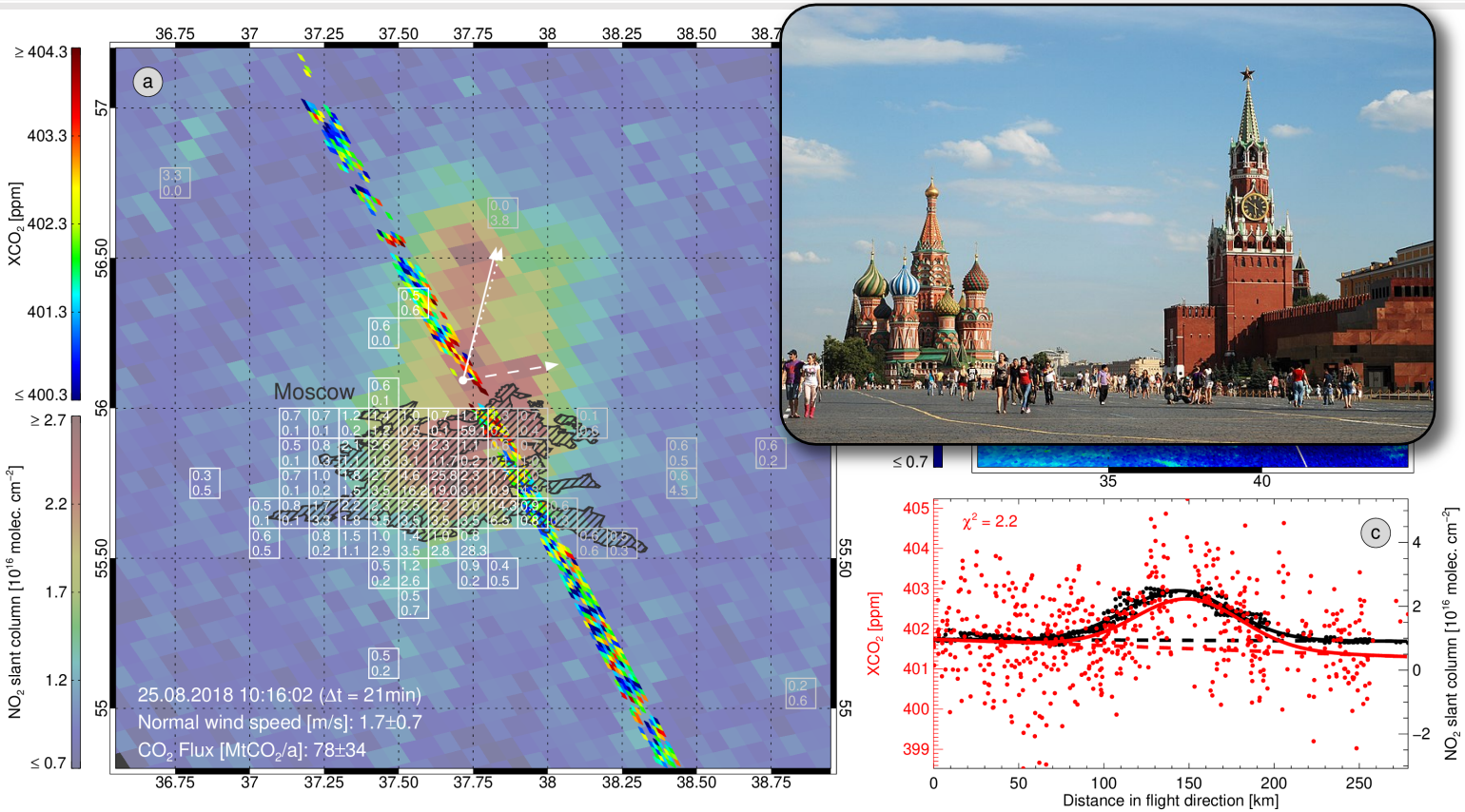
Point source flux estimates using combined OCO-2 XCO2 and S5P NO2 (Reuter et al., ACP, in prep)



XCO2 enhancement; NO2 enhancement, emissions databases not sure.

Gaussian fit of XCO2 data and normal wind speed result in a cross-sectional CO2 flux of 64±28Mt/yr

Point source flux estimates using combined OCO-2 XCO2 and S5P NO2 (Reuter et al., ACP, in prep)

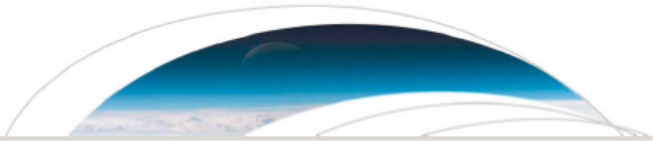


XCO2 enhancement; NO2 enhancement, emissions databases not sure.

Gaussian fit of XCO2 data and normal wind speed result in a cross-sectional CO2 flux of 64±28Mt/yr for Moscow.

AGU PUBLICATIONS

Geophysical Research Letters



RESEARCH LETTER
10.1002/2017GL074702

Key Points:
- The combustion of coal for electricity generation accounts for more than 40% of global anthropogenic CO_2 emissions
- Orbiting Carbon Observatory 2 observations can be used to quantify CO_2 emissions from individual coal power plants, in selected cases
- This work suggests that a future constellation of CO_2 imaging satellites could monitor fossil fuel power plant CO_2 emissions to support climate policy

Supporting Information:
- Supporting Information S1

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Quantifying CO_2 Emissions From Individual Power Plants From Space

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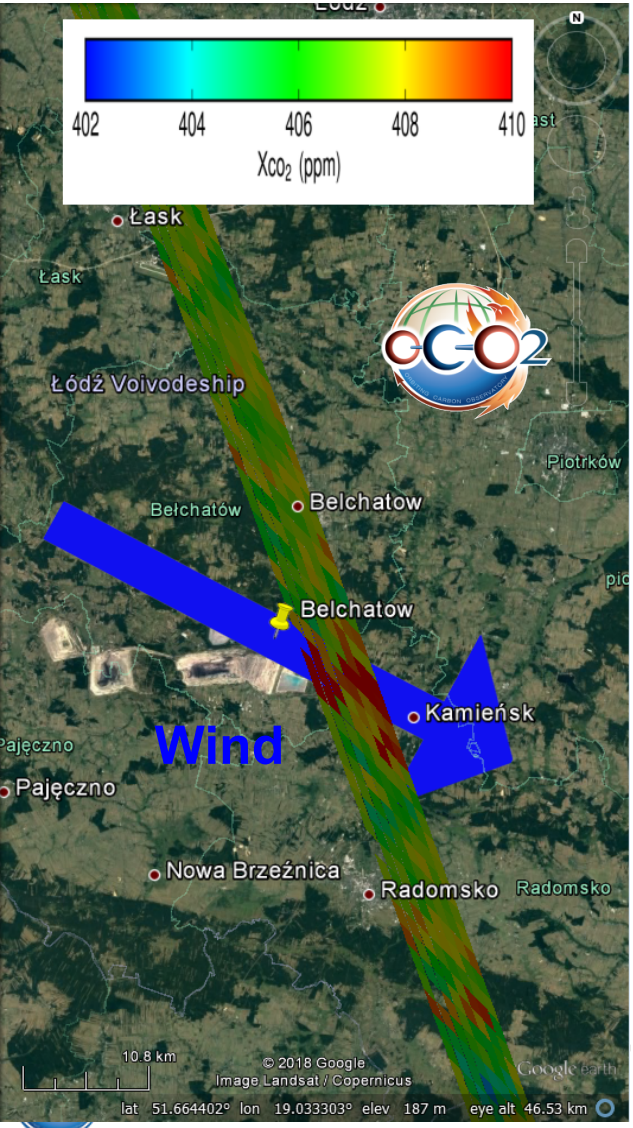
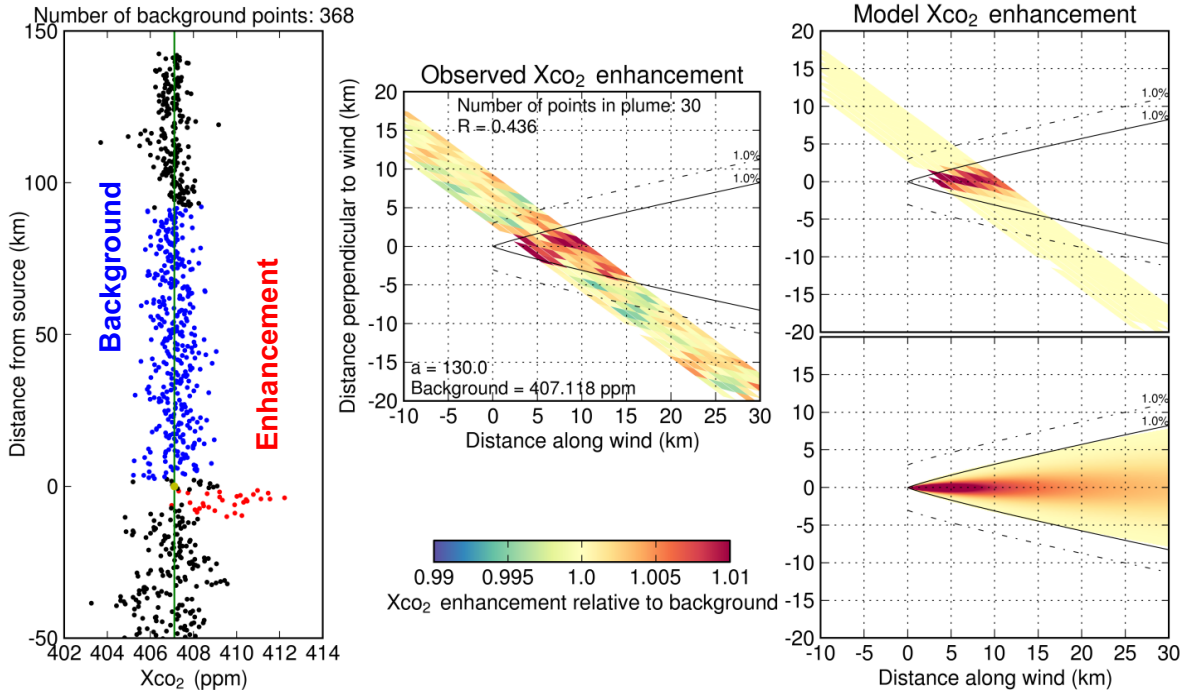
[1]Climate Research Division, Environment and Climate Change Canada, Toronto, Ontario, Canada, [2]Department of Physics, University of Waterloo, Waterloo, Ontario, Canada, [3]Air Quality Research Division, Environment and Climate Change Canada, Toronto, Ontario, Canada, [4]Department of Physics, University of Toronto, Toronto, Ontario, Canada, [5]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

Abstract In order to better manage anthropogenic CO_2 emissions, improved methods of quantifying emissions are needed at all spatial scales from the national level down to the facility level. Although the Orbiting Carbon Observatory 2 (OCO-2) satellite was not designed for monitoring power plant emissions, we show that in some cases, CO_2 observations from OCO-2 can be used to quantify daily CO_2 emissions from individual middle- to large-sized coal power plants by fitting the data to plume model simulations. Emission estimates for U.S. power plants are within 1–17% of reported daily emission values, enabling application of the approach to international sites that lack detailed emission information. This affirms that a constellation of future CO_2 imaging satellites, optimized for point sources, could monitor emissions from individual power plants to support the implementation of climate policies.

Europe's Largest Power Plant: Bełchatów

in coal region of Poland, in close proximity to COP24





Preliminary v9 CO_2 Emission Estimate: *89.6±21.6* ktCO_2/day

Error budget: wind speed uncertainty: ±2.6 kt/day
background uncertainty: ±1.3 kt/day
enhancement uncertainty: ±21.3 kt/day

Reported annual values converted to daily emissions:
CARMA for 2009 (72.3 kt/day), European Commission for 2013 (102 kt/day)

Ray Nassar, Callum McCracken, Cameron MacDonald, Matt Kiel

Call for Contributions to a Special Issue on Remote Sensing of CO_2 and CH_4

remote sensing

IMPACT FACTOR 3.406

Special Issue

Remote Sensing of Carbon Dioxide and Methane in Earth's Atmosphere

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Japan Agency for Marine-Earth Science and Technology
Dr. David Crisp
Jet Propulsion Laboratory, California Institute of Technology
Dr. Thomas Lauvaux
Pennsylvania State University

Website: www.mdpi.com/si/18603
Submission Deadline: 31 May 2019

Carbon dioxide (CO_2) and methane (CH_4) are the two most important greenhouse gases that have led to a significant fraction of the increase in earth's surface temperature in the past 100 years. This Special is dedicated to the past progress and new developments in satellite remote sensing of long-lived greenhouse gases, with a focus on CO and CH_4.

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